(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 1 270 224 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.01.2003 Bulletin 2003/01

(51) Int Cl.7: B41J 2/045

(21) Application number: 02013862.4

(22) Date of filing: 22.06.2002

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE TR
Designated Extension States:
AL LT LV MK RO SI

(30) Priority: 25.06.2001 JP 2001191800

(71) Applicant: Toshiba Tec Kabushiki Kaisha
Tokyo, 101-8442 (JP)

(72) Inventor: Kusunoki, Ryutaro
Chiyoda-ku, Tokyo 101-8442 (JP)

(74) Representative: Fuchs Mehler Weiss & Fritzsche
Patentanwälte
Söhnleinstrasse 8
65201 Wiesbaden (DE)

(54) Ink jet recording apparatus

(57) An ink jet recording apparatus according to the present invention includes a pressure chamber stored with ink, a nozzle communicating with the pressure chamber and capable of discharging the ink from the pressure chamber, and an actuator for increasing and reducing the capacity of the pressure chamber in response to driving signals from a driving signal generator (2). The driving signal generator (2) successively generate, an expansion pulse for increasing the capacity of the pressure chamber and a contraction pulse for reducing the capacity of the pressure chamber with a timing such that a time lag between the respective centers of the expansion pulse and the contraction pulse matches the resonance period of a meniscus generated in the nozzle by the ink in the pressure chamber. Thus, the ink jet recording apparatus continuously discharges a plurality of ink drops through the nozzle to form a pixel.

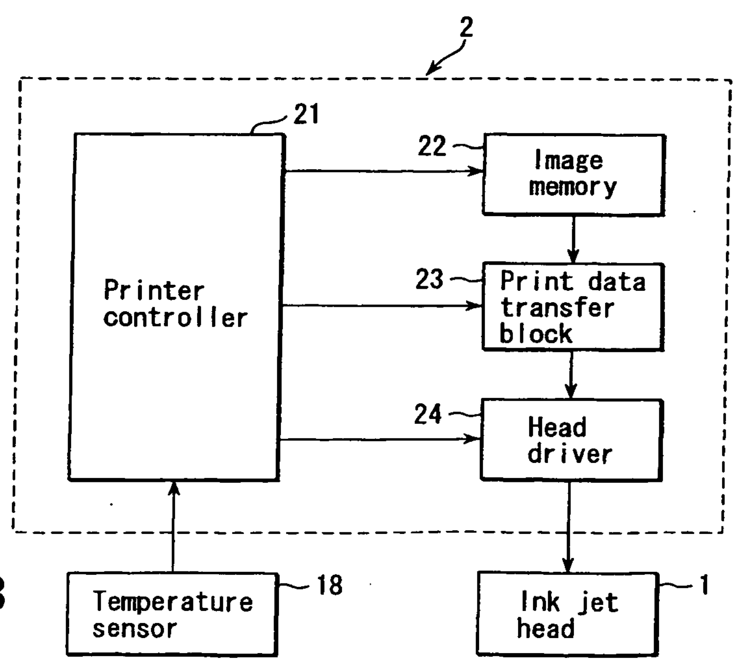


FIG. 3

Printed by Jouve, 75001 PARIS (FR)

Description

[0001] The present invention relates to an ink jet recording apparatus for gradational printing such that a plurality of ink drops are continuously discharged through nozzles.

[0002] Conventionally known is an ink jet recording apparatus in which an actuator composed of an electromechanical transducer such as an piezoelectric element is operated by means of driving signals to increase or reduce the capacity of a pressure chamber that is stored with ink, whereby the ink is discharged through nozzles to print a pixel by gradation. Ink jet recording apparatuses of this type are described in Jpn. Pat. Appln. KOKAI Publication No. 4-250045 and U.S. Pat. No. 5,461,493, for example.

[0003] In the ink jet recording apparatus described in Jpn. Pat. Appln. KOKAI Publication No. 4-250045, the voltage or pulse width of driving signals is changed to vary the volume of each ink drop that is discharged through a nozzle, whereby the dot size of each ink drop that is dashed against a recording medium can be changed for gradational printing.

[0004] In the ink jet recording apparatus described in U.S. Pat. No. 5,461,493, the number of driving pulses is controlled to discharge a plurality of ink droplets through nozzles and change the number of droplets to be discharged, whereby the dot size of each ink drop that is dashed against a recording medium can be changed for gradational printing.

[0005] In the case of the former gradational printing, it is hard considerably to change the volume of each discharged ink drop. Therefore, the latter gradational printing is superior to the former one in changing the dot size at a high rate.

[0006] In the latter gradational printing, compared with the former one in which the volume of one discharged ink drop is controlled to form one pixel, however, a plurality of ink droplets must be discharged at a higher driving frequency. In order to prevent lowering of the speed of the latter gradational printing, therefore, the droplets must be discharged by means of driving pulses with a considerably high frequency.

[0007] If these driving pulses are continuously applied to the actuator, vibration of meniscuses in the nozzles that are generated by means of driving pulses for discharging directly preceding ink droplets is followed by vibration of meniscuses that are generated by means of driving pulses for discharging subsequent droplets. Accordingly, the vibration of the meniscuses becomes so intensive and disturbing that ink in the nozzles involves air bubbles. If the ink in the nozzles thus involves air bubbles, the speed of discharge of ink drops lowers, and in some cases, no ink drops can be discharged.

[0008] The object of the present invention is to provide an ink jet recording apparatus capable of minimizing the possibility of ink in nozzles involving air bubbles even when gradational printing is carried out in a manner such that a plurality of ink droplets are continuously discharged to change the dot size.

[0009] An ink jet recording apparatus according to an aspect of the invention comprises a pressure chamber stored with ink, a nozzle communicating with the pressure chamber and capable of discharging the ink from the pressure chamber, an actuator for increasing and reducing the capacity of the pressure chamber in response to driving signals and continuously discharging a plurality of ink drops through the nozzle to form a pixel, and a driving signal generator for successively generating, an expansion pulse for increasing the capacity of the pressure chamber and a contraction pulse for reducing the capacity of the pressure chamber with a timing such that a time lag between the respective centers of the expansion pulse and the contraction pulse matches the resonance period of a meniscus generated in the nozzle by the ink in the pressure chamber.

[0010] This summary of the invention does not necessarily describe all necessary features so that the invention may also be a sub-combination of these described features.

[0011] The invention can be more fully understood from the following detailed description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a view showing the configuration of the principal mechanism of an ink jet recording apparatus according to an embodiment of the invention;
FIG. 2 is a sectional view of an ink jet head taken along line II-II of FIG. 1;
FIG. 3 is a diagram showing the configuration of a driving signal generator of the ink jet head;
FIG. 4 is a waveform showing an example of a driving signal generated from the driving signal generator;
FIG. 5A is a diagram showing a meniscus in an initial state;
FIG. 5B is a diagram showing a meniscus in a state of 0.5 Tc after start of operation;
FIG. 5C is a diagram showing a meniscus in a state of Tc after start of operation;
FIG. 5D is a diagram showing a meniscus in a state of 1.5 Tc after start of operation;
FIG. 6 is a graph showing change of ink pressure in a pressure chamber;
FIG. 7 is a graph showing the relation between driving voltage and a time lag between the respective centers of expansion and contraction pulses obtained when seven ink drops are continuously discharged;
FIG. 8 is a waveform showing another example of the driving signal generated from the driving signal generator;
FIG. 9 is a graph showing the relation between the respective speeds of discharge of ink drops at which ink is continuously discharged a plurality of times to form one pixel;

FIG. 10 is a waveform showing still another example of the driving signal generated from the driving signal generator; and

FIG. 11 is a waveform showing a further example of the driving signal generated from the driving signal generator.

[0012] An embodiment of the present invention will now be described with reference to the accompanying drawings.

[0013] FIGS. 1 and 2 are views showing the configuration of the principal mechanism of an ink jet recording apparatus. In these drawings, numeral 1 denotes an ink jet head 1. FIG. 2 is a sectional view taken along line II-II of FIG. 1.

[0014] The ink jet head 1 is formed by dividing a plurality of pressure chambers 11 for ink storage by means of partition walls 12. Each pressure chamber 11 is provided with a nozzle 13 for discharging ink drops. The base of each pressure chamber 11 is formed of a vibration plate 14. A piezoelectric member 15 is fixed on the base side of the vibration plate 14 corresponding to each pressure chamber 11. The vibration plate 14 and the piezoelectric member 15 constitute an actuator.

[0015] The ink jet head 1 is formed having a common pressure chamber 16 that communicates with each pressure chamber 11. Ink is injected from an ink supply unit (not shown) into the chamber 16 through an ink supply port 17, whereby the common pressure chamber 16, pressure chambers 11, and nozzles 13 are filled with ink. As the pressure chambers 11 and the nozzles 13 are filled with ink, a meniscus of ink is formed in each nozzle 13. Further, a temperature sensor 18 as a temperature detector is attached to the back of the common pressure chamber 16.

[0016] FIG. 3 is a block diagram showing the configuration of the principal mechanism of a driving signal generator 2 for driving the ink jet head 1. The principal mechanism of the generator 2 is composed of a printer controller 21, image memory 22, print data transfer block 23, and head driver 24.

[0017] The printer controller 21 loads the image memory 22 with print data and controls the print data transfer block 23 to transfer image data stored in the memory 22 to the head driver 24. The head driver 24 is controlled by the printer controller 21 to drive the ink jet head 1. Temperature information detected by the temperature sensor 18 is supplied to the printer controller 21.

[0018] If a driving signal is generated from the head driver 24 and applied to the piezoelectric member 15, according to this configuration, the piezoelectric member 15 displaces the vibration plate 14 to change the capacity of the pressure chamber 11. Thereupon, pressure waves are generated in the pressure chamber 11 to discharge ink drops through the nozzles 13. The resonance period of the ink meniscus in each nozzle 13 is equal to the Helmholtz resonance period of ink.

[0019] In the case where gradational printing is carried out according to the discharge frequency of ink droplets, the volume of ink droplets discharged in each cycle of operation should preferably be reduced to obtain high print quality. The shorter the Helmholtz resonance period of ink in the pressure chamber 11, moreover, the more quickly the ink drops can be discharged.

[0020] Since the Helmholtz resonance period of ink in the pressure chamber 11 can be increased by reducing the capacity of the chamber 11, it is to be desired that the capacity of the chamber 11 should be small enough.

[0021] FIG. 4 is a waveform showing an example of a driving signal that is generated from the driving signal generator 2. This driving signal is formed of driving pulses each including an expansion pulse P1 for increasing the capacity of the pressure chamber 11, a latency t, and a contraction pulse P2 for reducing the capacity of the pressure chamber 11. The gradational printing is carried out with the number of ink drops to be discharged through the nozzles 13 controlled according to the number of the driving pulses. A fixed delay time is set between the driving pulses.

[0022] If the Helmholtz resonance period of ink or the resonance period of the ink meniscus is defined as Tc, a time lag between the respective centers of the expansion pulse P1 and the contraction pulse P2 is adjusted to Tc. Further, the pulse width of the expansion pulse P1 and the contraction pulse P2 is adjusted to Tc/2. Therefore, t is also adjusted to Tc/2.

[0023] Since the resonance period Tc of the ink meniscus changes depending on temperature, the time lag between the expansion pulse P1 and the contraction pulse P2 can be compensated according to the temperature detected by the temperature sensor 18. The printer controller 21 is provided with TABLE 1, for example, and serves to correct the time lag between the expansion pulse P1 and the contraction pulse P2 according to the resonance period Tc that corresponds to the temperature detected by the temperature sensor 18.

Table 1

Temperature	Tc
10°C	4.4 μs
20°C	4.5 μs
30°C	4.6 μs
40°C	4.7 μs

[0024] If the resonance period Tc of the ink meniscus changes depending on the ink temperature, therefore, the time lag between the respective centers of the expansion pulse P1 and the contraction pulse P2 can be compensated correspondingly. Accordingly, the time lag between the respective centers of the expansion pulse P1 and the contraction pulse P2 can always be adjusted to the resonance period Tc of the ink meniscus.

[0025] The operation will now be described with ref-

erence to FIGS. 5A, 5B, 5C, 5D and 6.

[0026] If the expansion pulse P1 is applied to the piezoelectric member 15 in an initial state such that an ink meniscus m in each nozzle 13 is in the state shown in FIG. 5A, the pressure chamber 11 expand so that the ink pressure in the pressure chamber lowers in the manner shown in FIG. 6. Thereupon, the ink meniscus m receives a negative pressure from the pressure chamber 11 and starts to recede, as shown in FIG. 5B.

[0027] Thereafter, the ink pressure in the pressure chamber 11 is increased to become a positive pressure by pressure vibration in the manner shown in FIG. 6. In a time equal to 0.5 Tc after the start of operation, the ink meniscus m receives the positive pressure from the pressure chamber and ceases to recede, thereby coming to a standstill. Since the extension pulse P1 then also terminates, the pressure chamber 11 contracts. When the pressure chamber 11 starts to contract, the ink pressure further increases to the highest level, whereupon the meniscus m receives the high pressure and is discharged through the nozzle 13.

[0028] Thereafter, the ink pressure in the pressure chamber 11 is lowered by pressure vibration. In a time equal to Tc after the start of operation, the discharge of the meniscus m terminates under the negative pressure from the pressure chamber 11. At this point of time, the meniscus m is in the state shown in FIG. 5C. The ink discharge through the nozzle 13 is continued by inertia.

[0029] When the time Tc elapses after the start of operation, application of the contraction pulse P2 is started. Thereupon, the capacity of the pressure chamber 11 is reduced so that the ink pressure increases, and the negative pressure lowers. Thereafter, the meniscus m receives the negative pressure from the pressure chamber 11 and recedes, whereupon the ink pressure is increased by pressure vibration.

[0030] In a time equal to 1.5 Tc after the start of operation, the meniscus m receives the positive pressure from the pressure chamber 11, recedes, and then comes to a standstill. At this point of time, the meniscus m is in the state shown in FIG. 5D. The ink discharge through the nozzle 13 is further continued by inertia, and a first ink drop is discharged. Since the contraction pulse P2 then also terminates, the pressure chamber 11 expands. When the pressure chamber 11 starts to expand, the ink pressure lowers, whereupon most of the pressure generated for the ink discharge is canceled. Thus, sudden advance of the meniscus m is restrained, so that involution of air bubbles can be prevented.

[0031] If the next driving pulses are continuously applied, thereafter, the process of operation in the initial state and the subsequent processes are repeated. In the operation for discharging the second ink drop and the subsequent ink drops, the meniscus temporarily recedes much deeper than in the case of the discharge of the first ink drop. Since the ink is supplied from the common pressure chamber 16 to the pressure chamber 11 owing to the surface tension of the meniscus, however, the meniscus never continues to recede if the ink drop discharged in the first cycle of operation is small.

[0032] FIG. 7 is a graph showing the relation between a driving voltage V and a time lag between the respective centers of the expansion and contraction pulses P1 and P2 obtained when seven ink drops are continuously discharged. Curves g1 and g2 represent the upper and lower limits, respectively of the operating voltage.

[0033] The lower limit of the operating voltage is the lower limit of the driving voltage at which normal printing can be carried out. If the driving voltage is lower than this lower limit, the speed of discharge of ink drops is so low that the positions of impact of the ink drops vary substantially, and the printing density is too low to maintain satisfactory print quality. On the other hand, the upper limit of the operating voltage is the upper limit of the driving voltage at which the operation can be performed with stability. If the driving voltage exceeds this upper limit, the ink in the pressure chamber 11 involves air bubbles, so that ink drops cease to be discharged.

[0034] Further, the graph of FIG. 7 indicates that the highest driving voltage can be used for the drive when the time lag between the respective centers of the expansion and contraction pulses P1 and P2 is equal to Tc or the resonance period of a meniscus that is generated in each nozzle. This implies that the ink drops can be discharged at high speed with the least air bubbles involved when the time lag between the respective centers of the expansion and contraction pulses P1 and P2 is equal or approximate to Tc. Even if the time lag between the respective centers of the expansion and contraction pulses P1 and P2 is somewhat deviated from Tc, according to this graph, moreover, a relatively high driving voltage can be used for the drive in a relatively wide range, especially in the region higher than Tc, so that the same function and effect can be obtained.

[0035] It is to be desired, therefore, that the expansion and contraction pulses P1 and P2 should be generated so that the time lag between their respective centers is equal to Tc. However, the time lag need not always be equal to Tc, and may be somewhat deviated from Tc. In short, it is necessary only that the expansion and contraction pulses P1 and P2 be generated so that the time lag between their respective centers substantially corresponds to the resonance period of the meniscus in each nozzle.

[0036] According to this embodiment, the ink jet recording apparatus can minimize the possibility of the ink in the nozzles 13 involving air bubbles when one pixel is subjected to gradational printing by continuously supplying the actuator with a plurality of driving signals such that the time lag between the respective centers of the expansion and contraction pulses P1 and P2 is made substantially equal to the resonance period Tc of the meniscus.

[0037] Further, the ink jet recording apparatus can correct the time lag Tc between the respective centers of the expansion and contraction pulses P1 and P2 in

accordance with temperature information that is detected by the temperature sensor 18.

[0038] Although the driving pulses each of which is composed of the extension pulse P1 with the pulse width equal to Tc/2, the latency Tc/2, and the contraction pulse P2 with the pulse width equal to Tc/2 and which are repeatedly generated with the fixed delay time have been described as an example of the driving signal that the driving signal generator 2 generates, the present invention is not limited to these signals.

[0039] As shown in FIG. 8, for example, the driving signal generated from the driving signal generator 2 may be formed of driving pulses that are repeatedly generated without any delay time between them. In this case, generation of the contraction pulse P2 of one driving pulse is immediately followed by generation of the extension pulse P1 of another driving pulse.

[0040] If the delay time between the driving pulses is 0, as shown in FIG. 8, moreover, the speed of discharge of ink drops tends to increase according to number of ink drop, as indicated by curve g3 of FIG. 9.

[0041] To cope with this, a contraction pulse P2' with a pulse width shorter than Tc/2 may be used as the contraction pulse without changing the position of its center, as shown in FIG. 10. Alternatively, a contraction pulse P2" with a voltage V2 that is lower than the voltage V1 of the extension pulse P1 may be used as the contraction pulse, as shown in FIG. 11.

[0042] A moderate increase of the discharge speed allows an ink drop discharged at a time to unite with its preceding ink drop in the air, thereby improving the circularness of dots dashed against a printing medium. If the discharge speed is increased too much, however, the discharge sometimes may be unstable. In this case, it is necessary only that the pulse width or voltage of the contraction pulse be narrowed or lowered to restrain the increase of the discharge speed. By doing this, the increase of the speed of discharge of subsequent ink drops can be restrained to maintain the stability of the ink drop discharge, as indicated by curve g4 of FIG. 9.

Claims

1. An ink jet recording apparatus, which comprises a pressure chamber (11) stored with ink, a nozzle (13) communicating with the pressure chamber (11) and capable of discharging the ink from the pressure chamber, an actuator (14, 15) for increasing and reducing the capacity of the pressure chamber (11) in response to driving signals from a driving signal generator (2), and in which a plurality of ink drops are continuously discharged through the nozzle to form a pixel as the actuator (14, 15) is operated, **characterized in that**

   the driving signal generator (2) being capable of successively generating, as the driving signals, an expansion pulse (P1) for increasing the capacity of the pressure chamber and a contraction pulse (P2) for reducing the capacity of the pressure chamber with a timing such that a time lag (Tc) between the respective centers of the expansion pulse and the contraction pulse substantially corresponds to the resonance period (Tc) of a meniscus generated in the nozzle (13) by the ink in the pressure chamber (11).

2. An ink jet recording apparatus according to claim 1, **characterized by** further comprising a temperature detector (18) for detecting the temperature of the ink in the pressure chamber (11), and **characterized in that** the time lag (Tc) between the respective centers of the expansion pulse (P1) and the contraction pulse (P2) is compensated as the resonance period (Tc) of the meniscus generated in the nozzle (13) changes according to the temperature detected by the temperature detector (18).

3. An ink jet recording apparatus according to claim 1, **characterized in that** the width of the expansion pulse (P1) is adjusted to half of the resonance period (Tc) of the meniscus generated in the nozzle (13).

4. An ink jet recording apparatus according to claim 2, **characterized in that** the width of the expansion pulse (P1) is adjusted to half of the resonance period (Tc) of the meniscus generated in the nozzle (13).

5. An ink jet recording apparatus according to claim 1, **characterized in that** the width of the contraction pulse (P2) is shorter than the width of the expansion pulse (P1).

6. An ink jet recording apparatus according to claim 1, **characterized in that** the voltage (V2) of the contraction pulse (P2) is lower than the voltage (V1) of the expansion pulse (P1).

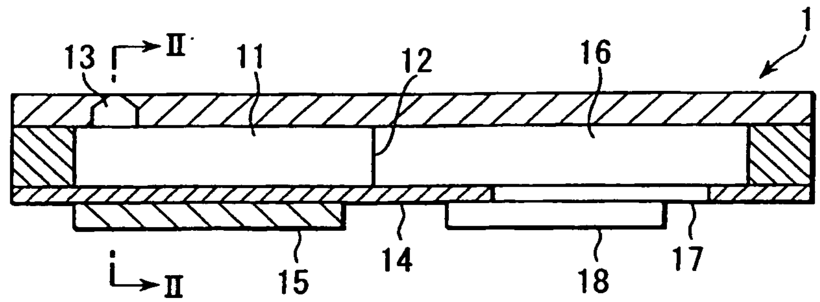


FIG. 1

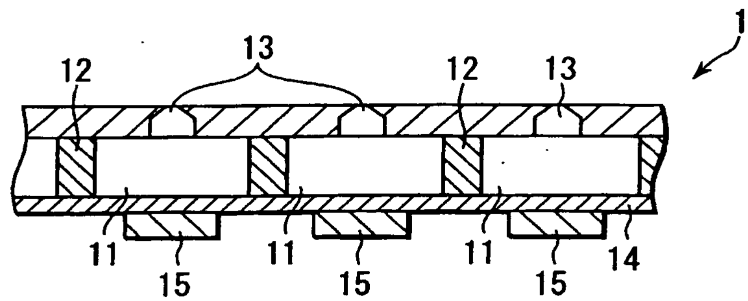


FIG. 2

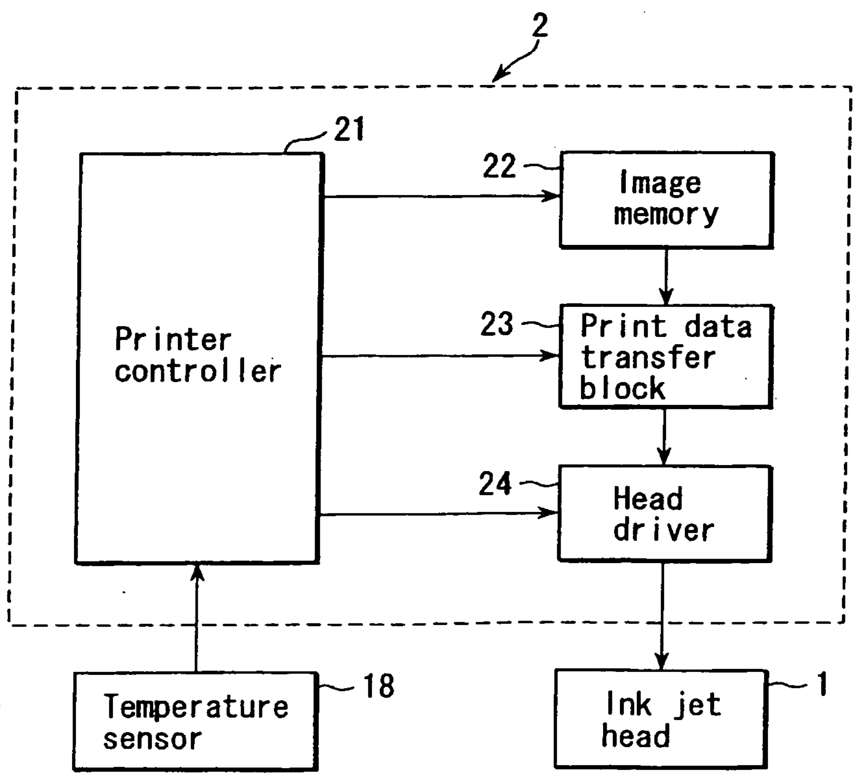


FIG. 3

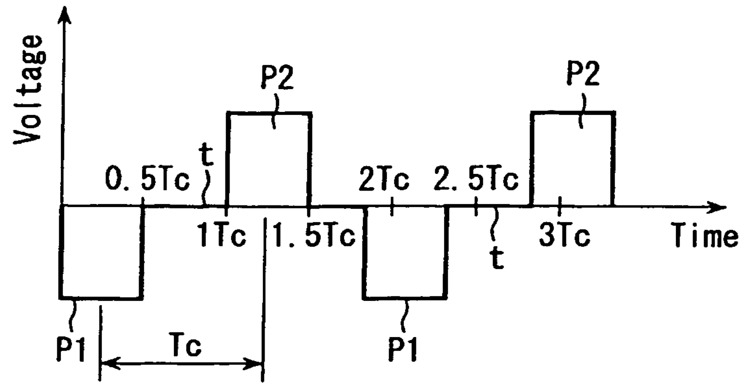
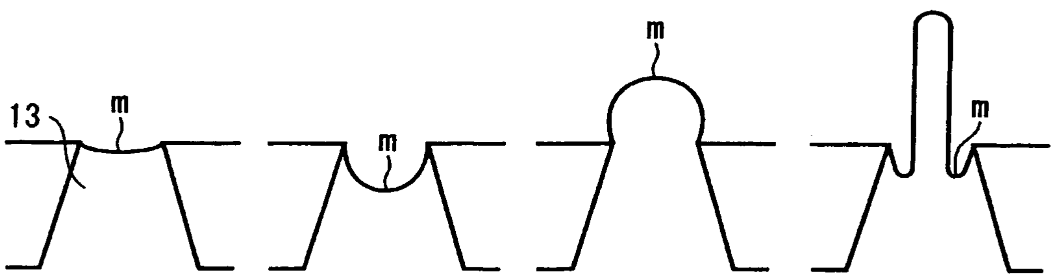


FIG. 4



Initial state

0. 5 Tc after start of operation

Tc after start of operation

1. 5 Tc after start of operation

FIG. 5A FIG. 5B FIG. 5C FIG. 5D

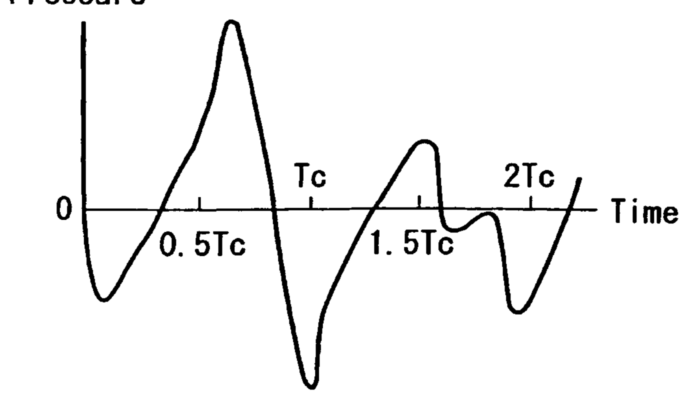
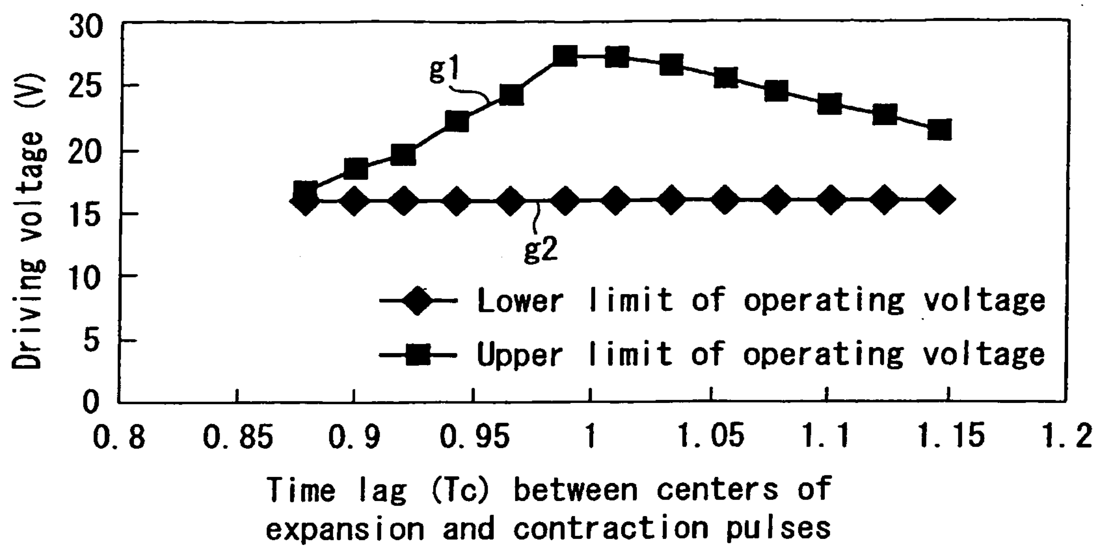
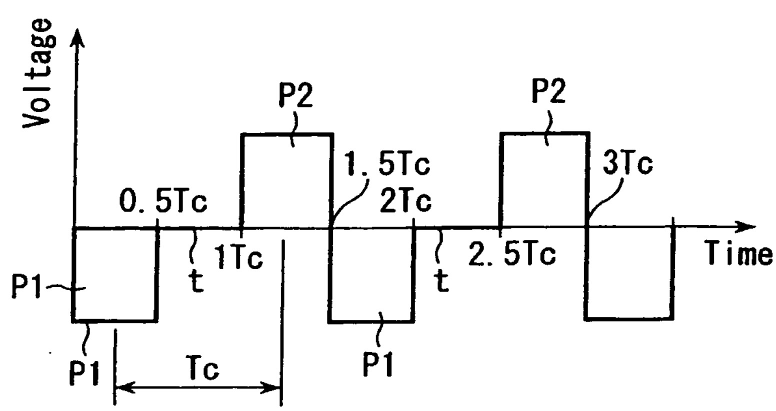


FIG. 6



30
25
20
15
10
5
0
Driving voltage (V)
g1
g2
Lower limit of operating voltage
Upper limit of operating voltage
0.8
0.85
0.9
0.95
1
1.05
1.1
1.15
1.2
Time lag (Tc) between centers of expansion and contraction pulses

FIG. 7



Voltage
P2
P2
1.5Tc
3Tc
0.5Tc
2Tc
1Tc
2.5Tc
Time
t
t
P1
P1
P1
Tc

FIG. 8

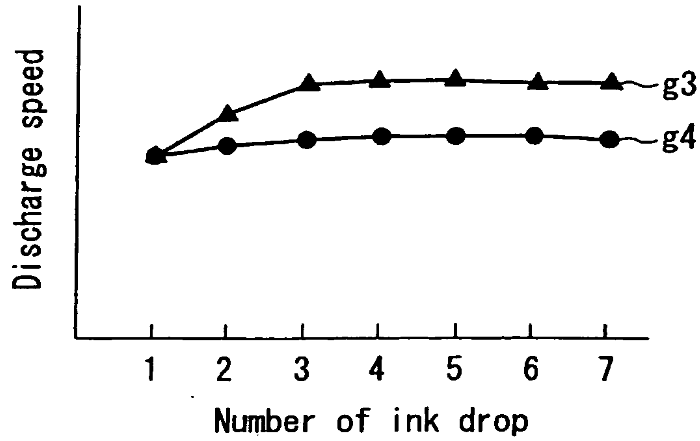


FIG. 9

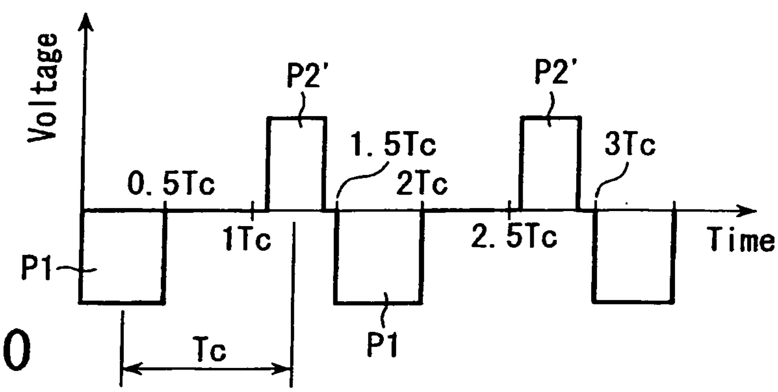


FIG. 10

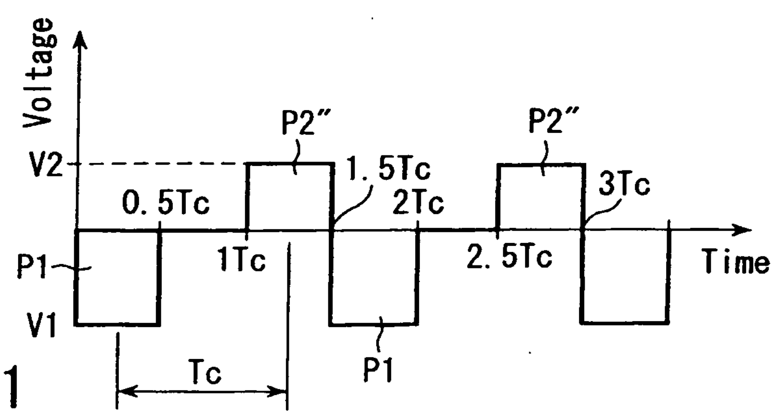


FIG. 11